Reducing relative humidity to control the house dust mite *Dermatophagoides farinae*

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Background: Indoor relative humidity (RH) is the key factor that determines the survival and population development of the house dust mite *Dermatophagoides farinae*. Maintaining RH below 50% is one recommendation in a comprehensive plan to reduce house dust mites and mite allergen levels in homes. Even when mean daily RH is reduced below 50%, RH may rise above 50% intermittently for brief periods because of activities in the home (eg, cooking, bathing, and ventilation).
Objective: The purpose of this study was to determine how brief daily periods of moist air alternating with long spells of low ambient RH (0% or 35%) influence population survival and growth of *D farinae*.
Methods: Population growth was determined for *D farinae* at daily RH regimens of 2, 4, 6, and 8 hours at 75% or 85% RH alternating with 22, 20, 18, and 16 hours at 0% or 35% RH.
Results: *D farinae* populations declined at daily regimens of 2 hours at 75% or 85% RH alternating with 22 hours at 0% or 35% RH. Daily regimens of 4, 6, and 8 hours at 75% RH alternating with 20, 18, and 16 hours, respectively, at 35% RH provided sufficient moisture for small growths in population size. These growths after 10 weeks were reduced by 98.2%, 98.0%, and 97.3% for daily regimens of 4, 6, and 8 hours, respectively, at 75% RH (with the remainder of the day at 35% RH) compared with the growth of populations continuously exposed to 75% RH. Continuous exposure to 85% RH inhibited population growth, but alternating daily regimens of 16, 18, and 20 hours at 35% RH allowed small populations to develop, although they were reduced by 99.4%, 98.8%, and 99.1% compared with population growth at a continuous 75% RH.
Conclusion: This study indicates that maintaining mean daily RH below 50%, even when RH rises above 50% for 2 to 8 hours daily, effectively restricts population growth of these mites and thus the production of allergen. To completely prevent population growth of *D farinae*, RH must be maintained below 35% for at least 22 hours per day when the daily RH is 75% or 85% for the remainder of the day. (J Allergy Clin Immunol 1999;104:852-6.)

Key words: *Dust mites, relative humidity,* Dermatophagoides farinae, *control, population*

Maintaining an indoor ambient relative humidity (RH) of less than 50% is recommended to control dust mites in human dwellings.[1] However, even when mean daily RH can be maintained below 50%, fluctuations in homes at times may raise RH above 50%. *Dermatophagoides farinae* has the remarkable ability to survive long dry periods (months) and even complete the life cycle when provided with brief periods of moist air daily.[2-6] The life cycle can be completed when mites are given daily RH regimens of 8 hours at 75% and 16 hours at 35%, 6 hours at 75% and 18 hours at 35%, 4 hours at 75% and 20 hours at 35%, and 8 hours at 75% and 16 hours at 0% RH. However, the time to complete the life cycle becomes significantly longer as the daily periods of moist air are shortened.[4] The times to complete the life cycles were 58.3 ± 1.44, 64.7 ± 1.87, and 82.4 ± 2.39 days for 8, 6, and 4 hours, respectively, of moist air daily (75% RH) with the remainder of the day at 35% RH compared with 41.1 ± 0.50 days at a continuous 75% RH. Given only 6 or 4 hours of moist air daily (75% RH) and 18 and 20 hours at 35% RH, 72.7% and 53.8%, respectively, of the larvae that emerged completed the life cycle.[4] Fifty-three percent and 44% of the larvae that emerged from eggs when given only 4 and 2 hours at 75% RH and 20 and 22 hours, respectively, at 0% RH daily survived 70 days. When the surviving larvae were transferred to a constant 75% RH, most completed the life cycle in normal time.[3] These studies clearly document that *D farinae* is well adapted for survival and development under fluctuating short hydrating and long dehydrating conditions. The purpose of this study was to determine the population dynamics of *D farinae* under similar conditions.

Abbreviation used
RH: Relative humidity

METHODS

Population growth of *D farinae* at hydrating regimens of 75% or 85% RH and dehydrating regimens of 0% RH

D farinae females were randomly selected from thriving laboratory cultures maintained at 75% RH and room temperature (20-22°C). The methods were as previously described.[2] Briefly, 40 female mites were placed into each of 192 culture chambers along with 50 mg of culture medium. The culture chambers consisted of 15-mL glass vials (Wheaton, Milville, NJ) closed with plastic snap-on ventilated (35 μm pore size nylon monofilament) lids that allowed gas exchange but prevented the mites from escaping. Sixteen culture vials were randomly assigned to each of the following 12 daily RH regimens at 20°C: (1) 2 hours at 75% and 22 hours at 0% RH, (2) 4 hours at 75% and 20 hours at 0% RH, (3) 6 hours at 75% and 18 hours at 0% RH, (4) 8 hours at 75% and 16 hours at 0% RH, (5) 24 hours at 75% RH, (6) 24 hours at 0% RH, (7) 2 hours at 85% and 22 hours at 0% RH, (8) 4 hours at 85% and 20 hours at 0% RH, (9) 6 hours at 85% and 18 hours at 0% RH, (10)

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TABLE I. Mean number of live (4 replicates except as noted) *D farinae* for populations held daily for different time intervals in moist air (75% or 85%) alternating with dry air (0% RH) at 20°C for 10 weeks

	2 weeks	5 weeks	10 weeks	19 weeks*
Control 75%	22.3 ± 5.9	83.5 ± 46.1	238.5 ± 108.0	4432.8 ± 4740.0
Control 0%	1.8 ± 2.4	0.3 ± 0.5	0.0 ± 0.0	13.5 ± 9.4
2/22	0.3 ± 0.5	0.5 ± 0.6	0.0 ± 0.0	3.3 ± 9.5
4/20	6.8 ± 4.9	12.8 ± 2.8	2.5 ± 3.3	6.8 ± 10.9
6/18	9.0 ± 5.9	15.8 ± 5.4	8.8 ± 5.7	10.0 ± 14.4
8/16	15.3 ± 4.5	20.8 ± 9.9	10.0 ± 5.7	21.0 ± 19.4
Control 85%	22.5 ± 1.9	**50.0 ± 33.9**	*23.0*	Mold growth
Control 0%	4.0 ± 5.5	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 1.0
2/22	3.3 ± 2.2	2.3 ± 3.3	2.5 ± 2.6	5.0 ± 8.1
4/20	16.8 ± 3.0	18.8 ± 13.9	5.5 ± 3.9	217.0 ± 106.8
6/18	11.3 ± 5.9	21.3 ± 9.9	6.0 ± 5.5	104.0 ± 56.2
8/16	17.8 ± 2.9	13.3 ± 13.0	10.3 ± 6.0	66.5 ± 62.8

All populations started with 40 *D farinae* females. Bold type indicates 3 replicates, and italic type indicates 1 replicate.
*After 10 weeks, populations were held at a continuous 75% RH to determine whether mites surviving 10 weeks of alternating conditions would recover and establish new populations.

8 hours at 85% and 16 hours at 0% RH, (11) 24 hours at 85% RH, (12) 24 hours at 0% RH.

Cohorts 1 to 4 and 7 to 10 were switched daily between hydrating (75% or 85% RH) and dehydrating (0% RH) conditions so that each cohort was held for the appropriate time in each RH condition. The 5th, 6th, 11th, and 12th cohorts were held continuously in the 75%, 0%, 85%, and 0% RH chambers, respectively, for 24 hours per day and served as the controls. At 2, 5, and 10 weeks after initiation of the cultures, 4 cultures were removed from each RH regimen. By using a stereomicroscope, all the live mites for each life stage (egg, larva, nymphs, and adult) were counted. After 10 weeks, the remaining cultures from the fluctuating RH regimens were exposed continuously to 75% RH for 24 hours per day and then analyzed at 19 weeks.

Population growth of *D farinae* at hydrating regimens of 75% or 85% RH and dehydrating regimens of 35% RH

Population growth was determined for the same 12 daily time-RH conditions as listed above, except that the dehydrating RH was 35% RH, and the temperature was 22°C. Two hundred forty cultures, each with 40 females and 50 mg of culture medium, were prepared as before but from different thriving laboratory cultures, and 20 of these cultures were assigned to each of the 12 daily RH regimens. For each daily regimen at 2, 5, 8, 10, and 14 weeks after initiation of the cultures, 4 culture vials were removed and analyzed for live mites for each life stage.

RH solutions and culture setup

The experimental humidity chambers (24.5 × 16 × 9 cm) were Rubbermaid (Wooster, Ohio) containers with sealing lids. In the experimental chambers RHs of 0%, 35%, 75%, and 85% were maintained with Drierite (W. A. Hammond Drierite Co Ltd, Xenia, Ohio), an 88% glycerol-water solution, saturated sodium chloride, and saturated potassium chloride, respectively. These solutions or Drierite were placed in the bottom of each humidity chamber. Cultures were placed on raised platforms inside each humidity chamber. RH in the chambers was monitored continually with HOBO hygrometers (Onset Computer Corp, Poccasett, Mass).

RESULTS

Starting populations of 40 *D farinae* females declined to a few surviving mites when given daily regimens of 2, 4, 6, and 8 hours of moist air (75% or 85% RH) and 22, 20, 18, and 16 hours of dry air at 0% RH for 10 weeks (Table I). During these periods, females produced eggs from which larvae emerged. A few of these immature and adult mites survived 10 weeks at these low moisture regimens (Figs 1 and 2). When subjected subsequently to 9 weeks at a constant 75% RH (weeks 10-19), none of the surviving mite populations previously exposed to these regimens of 75% and 0% RH recovered (Table I). The surviving mite populations previously exposed daily to regimens of 85% RH for 4, 6, and 8 hours and 0% RH for the remainder of the day increased 40, 17, and 7 times, respectively, by week 19 compared with week 10, when they were removed from the alternating regimens and held at a constant 75% RH (Table I). However, these increases were less than 5% of the size of the control populations held at a continuous 75% RH.

Populations did not increase when given 2 hours at 75% or 85% RH alternating with 22 hours at 35% RH daily for 14 weeks (Table II). In contrast, daily moisture regimens of 75% or 85% RH for 4, 6, and 8 hours and dehydrating air of 35% RH for 20, 18, and 16 hours provided sufficient moisture to support small population growth during the 14-week test period (Table II). Given regimens of 75% and 35% RH, population sizes at 14 weeks were directly related to the daily length of time exposed to 75% RH. However, after 10 weeks, population sizes for the experimental groups that were exposed to 4, 6, and 8 hours of 75% RH alternating with the remaining hours daily at 35% were 98.2%, 98.0%, and 97.3% smaller, respectively, compared with populations continuously exposed to 75% RH (Table II).

Continuous exposure of cultures to 85% RH inhibited population development, and these cultures developed visible mold growth. Populations increased when given regimens of 4, 6, and 8 hours at 85% RH alternating with 20, 18, and 16 hours at 35% RH, but their growth was significantly reduced compared with growth at a continuous 75% RH (Table II). No mold was visible in these cultures. This population growth was inversely proportional to the daily time in 85% RH, with the largest population growth

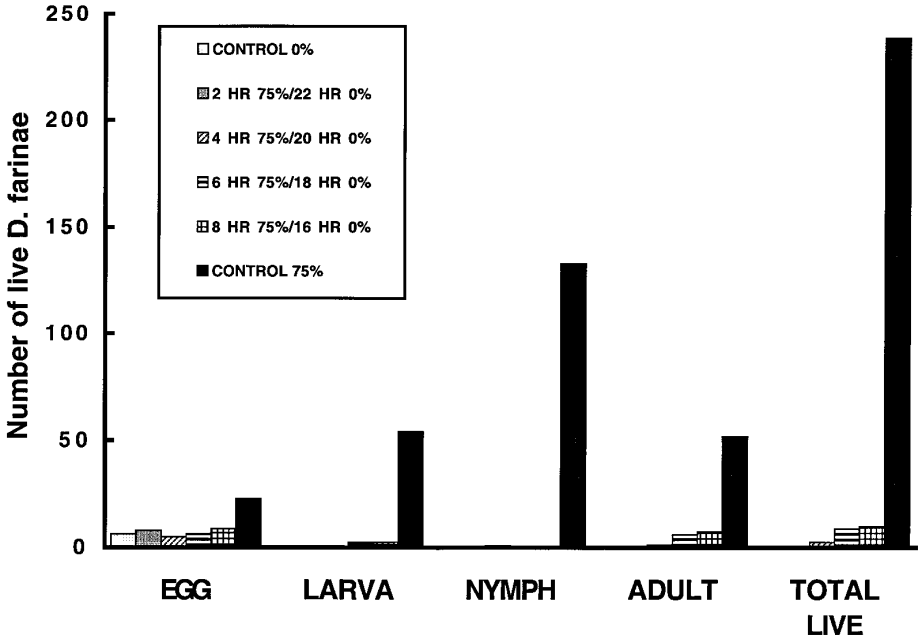

FIG 1. Mean number (live) of each life stage of *D farinae* for populations held in alternating daily regimens of 75% and 0% RH for 10 weeks at 20°C. The populations were started with 40 females.

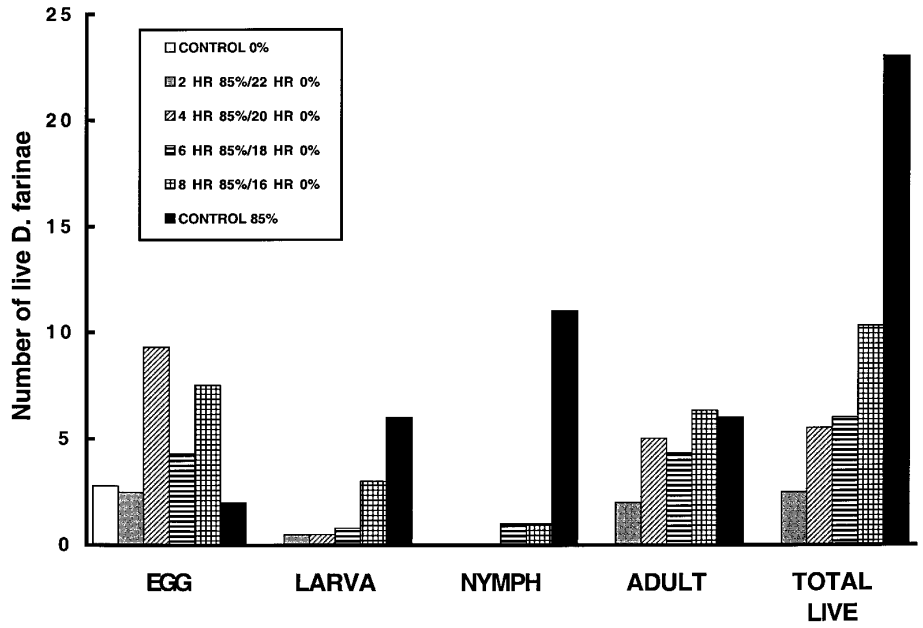

FIG 2. Mean number (live) of each life stage of *D farinae* for populations held in alternating daily regimens of 85% and 0% RH for 10 weeks at 20°C. The populations were started with 40 females.

occurring in the cultures given only 4 hours of moist air daily.

DISCUSSION

In homes in temperate climates, *D farinae* populations exhibit strong seasonal fluctuations in size.[7-11] Population size (density) peaks in the humid summer months when daily mean indoor RH is generally above 50%. The numbers of mites decline during the dry winter months when mean daily indoor RH is below 50%, although live mites are still recovered in dust samples. It has been hypothesized that dust mites survive the dry months as desiccation-resistant quiescent protonymphs and that this

TABLE II. Mean number of live (4 replicates except as noted) D farinae held daily for different time intervals in moist (75% or 85%) air alternating with dry air (35% RH) at 22°C

	2 weeks	5 weeks	8 weeks	10 weeks	14 weeks
Control 75%	176.3 ± 64.8	263.5 ± 189.0	329.5 ± 242.6	5943.0 ± 6620.4	TNC
Control 35%	8.0 ± 4.1	0.5 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
2/22	17.8 ± 8.8	31.8 ± 19.6	7.3 ± 8.7	9.0 ± 1.4	4.8 ± 7.5
4/20	63.3 ± 22.8	67.5 ± 9.9	57.0 ± 30.0	109.5 ± 72.0	247.0 ± 300.5
6/18	60.5 ± 24.7	77.0 ± 54.5	127.3 ± 52.5	**116.3 ± 99.8**	780.3 ± 516.4
8/16	58.0 ± 23.3	99.5 ± 54.3	97.3 ± 54.6	160.5 ± 184.5	2125.3 ± 1886.2
Control 85%	133.8 ± 25.4	46.5 ± 15.6	50.5 ± 53.1	**24.0 ± 37.3**	Mold growth
Control 35%	13.5 ± 6.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
2/22	34.5 ± 12.9	42.0 ± 8.0	29.8 ± 15.7	15.0 ± 7.0	20.8 ± 12.0
4/20	63.0 ± 24.3	67.5 ± 22.8	56.3 ± 32.4	55.5 ± 31.0	394.8 ± 633.3
6/18	47.0 ± 25.2	149.5 ± 126.6	37.5 ± 23.8	68.8 ± 69.9	230.3 ± 257.9
8/16	43.0 ± 19.4	70.5 ± 30.7	45.0 ± 19.0	33.0 ± 11.7	99.5 ± 103.6

All populations started with 40 *D farinae* females. Bold type indicates 3 replicates.
TNC, Too numerous to count.

life stage provides a breeding stock for development of large dust mite populations when indoor RH is more favorable.[8,12] However, life cycle studies indicate that low RH alone does not induce formation of this prolonged quiescent protonymph.[4,13,14] A prolonged quiescent protonymphal stage did not form during development under the same fluctuating RH regimens used in this study. Therefore on the basis of the results of this life cycle study, this life stage was not necessary for survival of the population during dry spells (dehydrating RH) for at least 10 to 14 weeks, alternating with daily brief periods of hydrating RH. A few *D farinae* survived at least 10 weeks at daily regimens of 2, 4, 6, and 8 hours of moist air at 75% or 85% RH alternating with 22, 20, 18, and 16 hours, respectively, at 0% RH. Some of these survivors established a growing population when given a continuous 75% RH, although these populations after 19 weeks were less than 5% in size compared with the population size of those grown at a continuous 75% RH for the same period of time at 20°C. This illustrates the remarkable ability of *D farinae* to survive dry conditions. However, this study showed that continuous exposure to RH of 0% or 35% at 20°C to 22°C inhibited long-term mite survival, which was expected because RH was continuously below the critical level.[15,16]

The fluctuating conditions in homes are likely not as extreme as the first conditions tested (0% RH for 16 to 22 hours). Therefore we examined population growth at 75% RH alternating with 35% RH, conditions that may occur in specific microhabitats in homes at any time but particularly during dry seasons and in tight homes in temperate climates when high-efficiency dehumidifiers are used with air conditioning (unpublished observations, Arlian LG). Mites survived and reproduced and populations increased in size when given a minimum of 4 hours daily at 75% or 85% RH, alternating with 20 hours of 35% RH. However, the sizes of these populations were reduced by more than 98% for both 75% and 85% RH compared with populations maintained at a continuous 75% RH after 10 weeks. Even the size of populations given 75% or 85% RH for 6 and 8 hours were less than 3% of the size of the population grown at a continuous 75% RH for 10 weeks. On the basis of the results of our previous life cycle studies, the reduced population growth results from a lengthening of the life cycle. These previous life cycle studies showed that low RH significantly extends the length of the life cycle in proportion to the length of time hydrating RH is given daily.[4] The longer life cycle results from the extended duration of the active and quiescent phases of each stage in the life cycle and is not due to the formation of a prolonged desiccation-resistant quiescent protonymph or other life stage.[3,4] It is not necessary to maintain a continuous low RH that will kill all mites because the lengthened life cycle will reduce mite populations and allergen production. Overall, our results indicate that when using dehumidification to control dust mites in homes, maintaining RH at or below 35% for 16, 18, 20, and 22 hours per day depresses population sizes by greater than 97% compared with populations grown at a constant 75% RH. Such reduction would significantly reduce the rate that mite allergen is produced and added to the allergen pool where mites reside in the home. What effect higher dehydrating RH (eg, 40% or 45%) alternated with moist air has on population growth remains to be determined. Presumably, if 40% or 45% RH was used instead of 35% RH, population growth rates would be greater as the dehydrating RH was increased. However, the reductions we observed at 35% RH were dramatic and suggest that even dehydrating regimens of 40% or 45% RH would result in significant depressions of mite population development compared with growth at a continuous 75% RH. Studies are necessary to determine whether *Dermatophagoides pteronyssinus* exhibits similar survival and population growth under fluctuating RH as *D farinae*. *D pteronyssinus* is less desiccation resistant and is likely to be more vulnerable to dehydration in fluctuating RH.

A second key finding of the study is that at a continuous 85% RH, populations declined or did not develop. However, given daily regimens of 85% RH alternating

with 35% RH, population increases were inversly proportional to the amount of time daily in 85% RH air. The greatest population growth occurred at 4 hours at 85% RH, alternating with 20 hours at 35% RH. Six and 8 hours of 85% RH alternating with 18 and 16 hours of 35% RH, respectively, resulted in smaller increases. These results suggest that too much moisture also directly or indirectly inhibits population development. Mold was observed in the cultures maintained at a continuous 85% RH, and it presumably inhibited mite growth. Small thriving populations did develop when daily regimens alternated between 85% and 35% RH, and no visible mold developed in these cultures. These results suggested that at a higher RH, alternating hydrating and dehydrating RH to minimize mold growth may be more favorable for *D farinae* population survival or development than a continuously high RH (eg, 85%) that promotes mold growth. This indirectly suggests that fungi are not necessary symbionts for mite survival.

These large differences between population growth under continuous and fluctuating RH conditions may partly explain the reported differences in mite densities between various mite habitats within and between homes in the same geographic areas.[7,17] Within and between infested homes, population densities vary significantly in carpeted floors between rooms and among carpets, couches, and mattresses. It is known that different RH or fluctuations in RH and different temperatures influence the developmental rates of *D farinae* and *D pteronyssinus*.[2,18-20] Within bedding, mattress surfaces, pillows, and couches, fluctuations occur regularly because of use. RH in mattresses drop and air temperature increases when beds are occupied.[5,6] However, the RH on the body surface (or within a few millimeters of it, particularly if there is some perspiration) may provide sufficient daily moisture for mite survival and breeding in occupied beds, couches, and chairs. Slab floors and floors over damp crawl spaces without proper moisture barriers may allow RH in carpets to rise above 50% at least some of the time, even when the ambient air is less than 50% RH. Temperature differences between cold surfaces (carpets on slab floors) and ambient air can result in an increase in RH approaching the dew point as humid ambient air is cooled in carpets. Temperature changes often occur in homes because residents change their thermostat setting to save energy, achieve their desired daytime and sleeping temperature preference, or to parallel their at-work versus their at-home schedules. Exhaled breath on a pillow or mattress for 4 to 8 hours daily would provide sufficient moisture for mites to breed on or near the surface of pillows during sleep. Showering-bathing, cooking, and opening windows all provide brief periods of moist air in specific locations.

In conclusion, this study indicates that maintaining a mean daily RH below 50%, even when RH rises above 50% for 2 to 8 hours daily, effectively restricts population growth of *D farinae* and thus the production of allergen. To completely prevent population growth of these mites, RH must be maintained below 35% for at least 22 hours per day when the daily RH is 75% or 85% for the remainder of the day. Thus daily fluctuations in humidity created by activities in a home would not preclude the use of dehumidification in a comprehensive plan to control dust mites in tight air-conditioned homes.

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